AD-A038 982 PHRASOR TECHNOLOGY PASADENA CALIF F/G 21/8.2

MECHANISMS OF EMITTER SURFACE DAMAGE DURING EHD COLLOID PARTICL--ETC(U)

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MECHANISMS OF EMITTER SURFACE DAMAGE

DURING EHD COLLOID PARTICLE GENERATION

AND ACCELERATION

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Interim Report for Period 1 February 1976 - 31 January 1977

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March 1977

Under Contract No. F44620-75-C-0056

Approved for Public Release
Distribution Unlimited



Prepared For:

Air Force Office of Scientific Research
Building 410
Bolling AFB, D. C. 20332



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## FOREWORD

This interim report was prepared by Phrasor Technology under Air Force Contract F44620-75-C-0056 titled "Mechanisms of Emitter Surface Damage During EHD Colloid Particle Generation and Acceleration".

The research reported herein was supported by the Air Force Office of Scientific Research. The program was monitored by Dr. Bernard T. Wolfson.

Work on this contract began in February 1975. The results of the studies and investigations performed during this second-year period are reported herein.

## CONTENTS

## 1. INTRODUCTION

This program is directed toward the understanding of the basic colloid thruster generation and acceleration process to determine the cause of performance degradation. Emitter surface changes due to erosion has been correlated with the performance degradation. During this report period, models of thruster emitter damage mechanisms were further established and shown to be in agreement with the physical evidence suggesting erosion by negative ion sputtering. The effects of a distribution of droplet sizes upon the erosion was extensively examined during this period.

## 2. RESEARCH OBJECTIVES

One of the research objectives of this program, was to identify that emitter damage mechanism which accounts for the physical damage experimentally measured. Once the erosion mechanism was selected, an analytical model that explains erosion was developed and was used in predicting the fundamental operational processes. The conduction of experiments was required to verify the underlying theory. Finally, an objective of this research is to utilize both the theoretical and experimental results to recommend new thruster design, operational improvements and directions for further investigations.

## 3. TECHNICAL PROGRESS SUMMARY

Charged liquid droplets are generated by the interaction between the liquid meniscus at the emitter tip of a colloid thruster and the intense electric field produced by the application of nominally high voltages to the high curvature geometry. A wide range of particle sizes are generated by this process extending from molecular ions to large liquid droplets. Under the conditions of normal coilloid thruster operation, approximately 10% of the generated current is composed of ions. The mean value of the charge-to-mass ratio of the droplets is low compared to that of the ions. The mean droplet, representing the distribution, has a radius of about 50 Å which is large compared to the ions. Because of their lower charge-to-mass ratio, the droplets travel with a velocity well below that of the ions when accelerated by the applied voltage. Thus the ions collide with the droplets and, at this velocity differential, deposit nearly all of their energy into the droplets. This results in droplet break up with a probable production of negative ions from the iodine present in the droplets. Calculations show that about $10^8$ collisions/sec occur, in the acceleration region just outside of the emitter, between ions and droplets. The negative ions are accelerated back to the emitter and cause sputtering and emitter erosion. With the assumed production of one negative ion for each ion/droplet collision, it is sufficient to explain the observed emitter erosion and the correlated degradation of performance. Calculations had been made assuming all the droplets to be at the same size of the mean charge-to-mass ratio.

To determine the effects of a distribution of particles further calculations were made. To begin with, the colloid charged liquid droplets accelerated from the source emitter consists primarily of charged droplets, and a small amount of molecular ions. The mean charge-to-mass ratio is $\overline{q/m} = 10^4$ coulombs/kg, while for the ions $q/m = 4.62 \times 10^5$ coulombs/kg. Since both groups are accelerated by the same electric potential, the ions will have a velocity higher by a factor of about seven than the droplets. The ions undergo collisions with the droplets at a rate which is a function of the distance traversed through the (relatively motionless) droplets.

The collision rate $\beta$ for an initial ion current of $I_o$ is given by:

$$\beta(x) = \frac{I_o - I(x)}{e}, \text{ collisions/sec,} \qquad (1)$$

where $I(x)$ is the current at position x and e is the electronic charge. The reduction in ion current, dI, after traversing a distance, dx, through the droplets is given by:

$$dI = -I \left[ \sum_i \sigma(r_i)\ n(r_i) \right] dx, \qquad (2)$$

where, $\sigma(r_i)$ is the collision cross section $(\pi r_i^2)$ of the droplets that have a radius, $r_i$, and $n(r_i)$ is the particle number density of these same droplets. The quantity, $\alpha = \Sigma\sigma(r_i)n(r_i)$, represents the "absorption"

coefficient of the ions. The particle number density is given by:

$$n(r) = \frac{\dot{N}_r}{Av_r} , \tag{3}$$

where A is the total cross sectional area of the ion beam, $v_r$ is the velocity of those droplets having a radius r, and $\dot{N}_r$ is the flow rate (particles/sec) of those droplets having a radius r. The velocity acquired by the droplets depends upon the charge-to-mass ratio, q/m, and the electrical potential difference, $\Delta V$ according to

$$v = \left(2 \frac{q}{m}\right)^{1/2} \Delta V^{1/2} \tag{4}$$

The potential difference $\Delta V$ represents the potential through which each of the charged particles are accelerated. The potential function that best represents the geometry of needle emitters is nonlinear and integration techniques are required to finally calculate the total number of collisions in the acceleration region.

According to Rayleigh's criterion, the maximum charge-to-mass ratio of a droplet is related to its radius by:

$$\frac{q}{m} = \left(\frac{9\gamma\epsilon_o}{\rho^2}\right)^{1/2} r^{-3/2} , \tag{5}$$

where, $\gamma$ is the surface tension of droplet, $\rho$ is the density of droplet and $\epsilon_o$ is the permittivity of free space. Using the appropriate potential function along with Eq. (5) the value of the velocity, Eq. (4), could be obtained as a function of the droplet radius and the droplet material properties.

If the charge-to-mass ratio is distributed normally the probability density function of q/m can be given by:

$$f(q/m) = \frac{1}{s(2\pi)^{\frac{1}{2}}} e^{-\frac{1}{2}\left(\frac{q/m - \overline{q/m}}{s}\right)^2} \qquad (6)$$

where, s and $\overline{q/m}$ are the standard deviation and mean value respectively, of the distribution. Since $\dot{N}$ denotes the total flow rate of the droplets, then $\dot{N}_r$ the flow rate for a given size droplet could be obtained from the normal distribution Eq.(6). Using this distribution with a change of variables to obtain $\dot{N}_r$ as a function of r along with Eq.(5), then n(r), Eq.(3), can be given as a function of the droplet radius and the potential function. The absorption coefficient is the summation (or integral) of the product $n(r)\sigma(r)$ over the entire range of droplet sizes as indicated in Eq.(2).

The current I(x) is obtained by solving Eq.(2) integrated over the entire voltage range of the accelerating field, and integrated over the range of droplet particle sizes. The charge-to-mass distribution extended over three standard deviations and covers 99.73% of all the values of charge-to-mass ratios. For the case of a standard deviation of 3,000 coulombs/kg the upper and lower limits of integration were 19,000 and 1,000 coulombs/kg.

A wider normal distribution having a standard deviation of 3,300 coulombs/kg was also calculated. In addition, a chi-squared distribution was used which is skewed compared with a normal distribution.

Figure 1 shows one of the normal distribution and the chi-squared distribution. Table I shows a comparison of the results for a normal distribution having a zero standard deviation (a delta function), two of the regular normal distributions and the chi-squared distribution. All of these calculations were based upon a total acceleration potential of 13kV, and each have the same mean value. The collision rates increase with increasing widths of the distributions. They range over a factor of about four, but the range is sufficiently narrow so as to explain the required collision rate and explain the measured erosion.

TABLE I

SUMMARY OF RESULTS

| Probability Density Function, f(q/m) | Mean q/m (coulombs/kg | Standard Deviation (coulombs/kg) | Ion Collision Rate (collisions/sec) |
|---|---|---|---|
| Normal (Gaussian) | 10,000 | 0; constant droplet velocity | $1.9 \times 10^8$ |
| Normal (Gaussian) | 10,000 | 3000 | $3.3 \times 10^8$ |
| Normal (Gaussian) | 10,000 | 3300 | $6.0 \times 10^8$ |
| Chi-squared | 10,000 | 7071 | $7.9 \times 10^8$ |

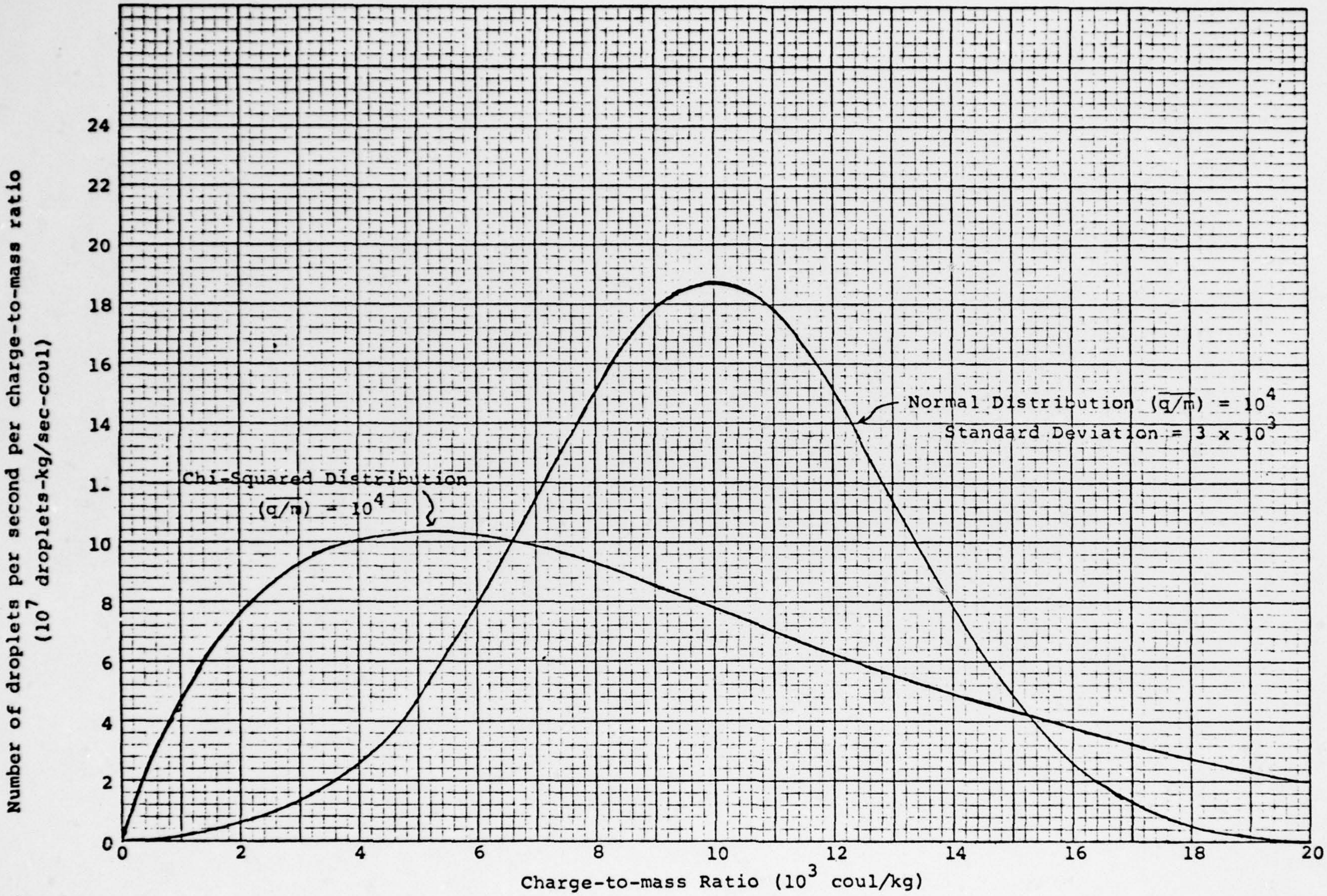


Fig. 1 The Distribution Functions

## 4. RECOMMENDATIONS AND CONCLUSIONS

The model developed to explain the degradation of performance and correlated emitter erosion appears to be self-consistent. No unusual assumptions were made and the rates used in the calculations are moderate in value. Only the production of negative ions resulting from the collisions between positive ions and the large sodium iodide doped glycerine droplets has not been verified. The inclusion of several distributions of droplet sizes in the calculations did not greatly affect the results in terms of the collision rate. The physics of droplet generation, stability, and break up was studied and appears to be useful for application to other problems involving small liquid droplets. The most important aspect of the model that remains uncertain is the production of negative ions which the future laboratory task is designed to verify.

The information generated on this program from the modeling of the emitter damage process leads to the following recommendations to minimize emitter erosion:

a. Eliminate the production of positive ions in the charged particle distribution.

b. Use a conductive dopant in the propellant that does not contain iodine or an element with high electron affinity.

c. Replace platinum/iridium with an emitter material that sputters less.

d. Operate thruster at lower voltages.

## 5. MEETINGS AND REPORTS

A paper was presented at the AIAA 12th Electric Propulsion Conference in Key Biscayne, Florida, November 1976. The paper, based upon the present program, was entitled "Particle Interactions in the Colloid Thruster Exhaust Plume", AIAA Paper #76-1056.

A presentation on the status of the program was made at the AFOSR Contractors Meeting on Electric Propulsion, 7 March 1977, in Lancaster, California.

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## REPORT DOCUMENTATION PAGE

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| | | |
|---|---|---|
| 1. REPORT NUMBER<br>AFOSR - TR - 77 - 0540 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (*and Subtitle*)<br>MECHANISMS OF EMITTER SURFACE DAMAGE DURING EHD COLLOID PARTICLE GENERATION AND ACCELERATION. | | 5. TYPE OF REPORT & PERIOD COVERED<br>INTERIM<br>1 Feb 76 - 31 Jan 77<br>6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>JULIUS PEREL<br>JOHN F. MAHONEY | | 8. CONTRACT OR GRANT NUMBER(s)<br>F44620-75-C-0056 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>PHRASOR TECHNOLOGY<br>110 S EUCLID AVE<br>PASADENA, CALIFORNIA 91101 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>9752-02<br>61102F |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>AIR FORCE OFFICE OF SCIENTIFIC RESEARCH/NA<br>BLDG 410<br>BOLLING AIR FORCE BASE, D C 20332 | | 12. REPORT DATE<br>March 1977<br>13. NUMBER OF PAGES<br>12 |
| 14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*) | | 15. SECURITY CLASS. (*of this report*)<br>UNCLASSIFIED<br>15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

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| COLLOID THRUSTER | DROPLET STABILITY |
| ELECTRIC PROPULSION | CHARGED DROPLETS |
| NEGATIVE ION | PARTICLE COLLISIONS |
| SPUTTERING | PARTICLE DISTRIBUTION |
| ELECTHOHYDRODYNAMICS | |


20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A model of emitter tip erosion has been developed that correlates with performance degradation. The erosion is caused by back bombardment of the emitter by negative ions produced from the break up of slow droplets as a result of collisions with fast ions. Calculations are made assuming the droplets are all the same size rather than using the distribution of droplet sizes actually observed. If at least one negative ion is produced at each ion/droplet collision the resulting sputtering date is suficient to explain the measured erosion. The recent investigations have been devoted to the effects of including a distribution of


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droplet sizes in the analysis. A normal distribution of the change-to-mass ratio was chosen with a standard deviation of about one-third of a mean charge-to-mass ratio of $10^4$ coul/kg. This approximates the distribution observed experimentally. Results of the analysis shows that the calculated collision rate increases when the droplet propulation is changed from uniform size to the assumed distribution. The effects of varying the distribution were examined by changing the standard deviation and by replacing the normal distribution by an unsymmetrical distribution. The results indicate that the number of ion/droplet collisions increases with increases in the width of the droplet size distribution. The collision frequency, over the range of distributions examined, was always sufficient to explain the measured erosion.